Carderock Division
Naval Surface Warfare Center
Bethesda, Md. 20084–5000

CARDIVNSWC–TR–61—95/12 June 1995
Survivability, Structures, and Materials Directorate
Technical Report

Interaction of Ship and Dock Cathodic Protection Systems Predicted From Potential Measurements of a Seawall at Panama City, Florida

by
Harvey P. Hack and Dana C. Lynn

Approved for public release; distribution is unlimited.

CARDIVNSWC–TR–61—95/12
Interaction of Ship and Dock Cathodic Protection Systems Predicted From Potential Measurements
of a Seawall at Panama City, Florida

4

Carderock Division
Naval Surface Warfare Center
Bethesda, Md. 20084–5000

CARDIVNSWC–TR–61—95/12 June 1995

Survivability, Structures, and Materials Directorate
Technical Report

Interaction of Ship and Dock Cathodic Protection Systems Predicted From Potential Measurements of a Seawall at Panama City, Florida

by
Harvey P. Hack and Dana C. Lynn

ABSTRACT

Carderock Division, Naval Surface Warfare Center technologists took potential (voltage) measurements on a seawall located at the Naval Coastal Systems Center in Panama City, FL to determine whether a large cathodic protection system on a pier or dock could cause stray current corrosion or cathodic protection control problems on a ship docked to the structure. The measurements were taken because, while the protection system on the seawall was providing adequate protection, one rectifier was not working properly.

Minimal local potential gradients were found near the seawall anodes. This should have had no effect on ships docked with the use of bumpers, which provide spacing of at least 0.5 m from the seawall. Rectifier shutdown or inadequate rectifier balance of the same potential can lead to potential differences over distances of roughly ship length proportions to cause control problems on a ship's cathodic protection system. To avoid this, multiple seawall rectifiers should be periodically checked for proper operation and balanced to the same control potential. A ship should not be docked so that it bridges the area between two rectifiers that are not properly balanced to the same potential.

CONTENTS

FIGURES

ADMINISTRATIVE INFORMATION

This project was funded under the Surface Ship Materials Technology Program sponsored by the Office of Naval Research and managed by Mr. Ivan Caplan. The work was performed under program element 62761N, task area SF61541–591, and work unit 1–2803–162. Work was conducted in the Marine Corrosion Branch; Carderock Division, Naval Surface Warfare Center (CARDEROCKDIV, NSWC) under the direction of Mr. Robert J. Ferrara.

ABBREVIATIONS

CARDEROCKDIV, NSWC	Carderock Division, Naval Surface Warfare Center
ROV	Remote-operated vehicle

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of M.L. Nuckols of the U.S. Naval Academy and Victor Dilling and Dennis Bernard of CARDEROCKDIV, NSWC for conducting the pier measurements.

INTRODUCTION

Ship-impressed current cathodic protection systems rely on a potential (voltage) measurement of one or, at most, a few reference cells to determine the output of the power supplies for the anodes. Impressed current cathodic protection systems are designed assuming the ship is located in an environment without potential gradients. However, if the ship is, instead, located in an environment with a potential gradient, areas of the hull far from the reference cells will experience potentials different from those expected by an amount equal to the magnitude of the potential difference between those areas and the areas near the reference cells. If the potential gradient is sufficient, this can lead to either overprotection, with resultant coating blistering, or underprotection, with resultant corrosion. Alternatively, potential gradients might lead to stray current corrosion, even on cathodically protected ships.

Piers and docks to which ships tie up are sometimes made from steel or steel-reinforced concrete. The cathodic protection that is sometimes used to prevent these shore structures from corroding will generate potential gradients in the water near these structures. Ships docked near these structures may, therefore, experience potential gradients for which their cathodic protection systems were not designed. Alternatively, the ship cathodic protection system could generate potential gradients that lead to corrosion of the shore structure, particularly if the shore structure is only marginally protected or, in fact, totally unprotected.

The purpose of this study was to determine the magnitude of the potential gradients generated by a large, impressed current cathodic protection system on a shore structure to which ships tie up. From this information, conclusions regarding the likelihood of unfavorable interaction between the ship and shore structure cathodic protection systems should be possible.

REMOTE-OPERATED VEHICLE BACKGROUND

A remote-operated vehicle (ROV) is an unmanned underwater vehicle made up of thrusters, an underwater camera, control electronics, and a tether, which provides power and electrical signals to the vehicle. Most ROVs contain a magnetic compass and depth sensor, which provide heading and depth control, respectively. To provide the additional control functions required to position the ROV accurately relative to the seawall, a much more sophisticated control system was developed.

The Deep Ocean Systems Branch of CARDEROCKDIV, NSWC was originally tasked to develop an underwater ROV and control system for performing acoustic diagnostics on submarines. The purpose of the ROV was to position various sensors and serve as a platform for a data acquisition system. The system was patented in September 1991.*

Most ROVs are controlled by a human operator using a joystick controller to activate the various thrusters on the ROV so that it can dive, go forward, turn, etc. Lack of visibility in a harbor means that the operator does not have visual points of reference to use, and, although depth and heading may be known, it is difficult to determine location. A precision underwater navigation system was incorporated to detect the location of two target transceivers mounted on the top of the ROV. A PC computer-based control system

*U.S. Pat. No. 5,047,990.

receives the three-dimensional position data from the navigation transceivers and translates it into a vehicle position and heading. This position is then compared with the desired ROV position, and the appropriate thrusters are activated to move the ROV to that position. When the vehicle arrives at the desired point, the control system enters a hover phase so the vehicle will maintain that position until instructed to move.

The ROV team uses a 20-ft truck with electric generators, a boom crane, instrumentation, spare parts, and automated data logging computers. After the truck is parked and unpacked, the instrumentation is set up and the navigation transceivers are set out for the ROV control system. The boom crane is used to lower the ROV into the water.

The ability to position accurately allows the ROV to perform many functions that divers cannot do, e.g., in the highly turbid waters of most harbors where visibility is very poor and visual points of reference cannot be relied on to navigate. The ROV control system will display the position of the ROV at all times, and the navigation system allows for correlation of the ROV's position with the sensor data taken during the deployment. In this manner, data can be presented graphically, annotating individual data points on a profile of the ship's hull or seawall and generating three-dimensional profiles of the data.

CARDEROCKDIV, NSWC has used a wide range of ROV deployments. The initial ROV deployments were to conduct acoustic diagnostic surveys. Later, a magnetic and electrical potential survey was performed. The most recent deployments have been monitoring the performance of the impressed current cathodic protection systems on aircraft carriers. Most ROV deployments take place at Navy shipyards, commercial shipyards, or other industrial marine environments. ROV deployments have taken place in Port Canaveral, Port Everglades, Panama City, and Mayport, FL; Norfolk, VA; Mobile Bay, AL; and Bremerton, WA. These deployments have proven that thorough surveys of various types can be performed with ROVs on naval structures in an effective manner producing data that could not be obtained by other means.

PROCEDURE

A structure was chosen based on the following criteria:

1. The cathodic protection system on the structure should generate large currents, and the structure, itself, should be large enough to maximize the possibility of generating large potential gradients.
2. The structure should be located in full strength seawater.
3. The structure should be of a configuration that is conducive to ships tying up in close proximity and preferably be one which ships do occasionally tie up near.
4. The structure should be located in an area where access by Navy personnel for experiments is possible.
5. The structure should be relatively free of nearby ships during the measurements.
6. The cathodic protection system on the structure should be operating properly.

The structure chosen was a seawall located at the Naval Coastal Systems Center in Panama City, FL. Figure 1 shows the relationship between the seawall (designated as east dock and south dock), St. Andrew Bay, and Alligator Bayou.

Figure 2 shows the detailed layout of the seawall. Roman numerals are used as labels for the six rectifiers. The first three were used to protect the east dock where most of the potential measurements reported herein were taken; the last three were used to protect the south dock. Each rectifier supplied multiple anodes, spaced at roughly 5-m intervals. Each rectifier was used to protect roughly 67 m of seawall on the east dock, and slightly more on the south dock. Each anode was placed against the seawall at a depth of roughly 3.65 m.

The seawall was constructed of corrugated steel sheet, with the square corrugations of 40.6 cm spacing and 40.6 cm depth. Thus, the effective surface area of the seawall for cathodic protection was twice the apparent surface area based on linear dimensions. The top of the seawall was capped with concrete, covering roughly the top 0.2 m of seawall below the water surface.

Water depth varied depending on the tide cycle between about 5.0 and 6.0 m. First, a series of potential readings was taken along the seawall at three depths: roughly mid–anode, near the surface, and halfway between. These were taken by hanging a weighted, basket-style Ag/AgCl reference electrode at measured distances down from the dock edge and back-calculating water depth from the known depth of the water surface during the first measurement. Because all measurements were made relative to the seawall, their depth was constant relative to the anode position but varied relative to the water surface. Later measurements away from the seawall were made with an ROV affixed with a similar reference cell.

The ROV was used as a platform for placing the reference cell accurately at positions far from the seawall. The ROV has the capability of going to any specified point in the water column and hovering there while measuring the potential. A photograph of the ROV is included as Figure 3. Attempts were made to match depths of these measurements with the dipping cell measurements next to the seawall, with the addition of another measurement near the bottom; however, tide variations made this matchup only approximate. The east corner of the east dock area was designated as the reference point for all measurements along the seawall, with the intersection of the east and south docks falling at roughly 200 m.

The first ROV measurements were taken on the east dock near the intersection with the south dock and in an area between two of the anodes. The purpose of these measurements was to determine the local potential field near and between the anodes. The anode at the X=0 position was located at a reference distance of 181.7 m from the east corner of the east dock. Potential measurements were taken at the four depths discussed previously at spacings of 1 m along the seawall for a total of 6 m. This was sufficient to pass the location of the neighboring anode, which was roughly 5 m away. ROV measurements were taken at 0.25-, 0.5-, 1.0-, and 1.5-m distances away from the seawall, thus making a three-dimensional grid of points between the two anodes.

Next, a series of potentials was measured on a line starting close to the bottom near the anode at X=0 and extending perpendicular from the seawall at the same depth for almost 10 m. This run was repeated twice. The purpose of this measurement was to see at

what distance from the seawall the potential deviation due to the anode would become negligible.

The last set of measurements was a grid similar to the first grid but located with an X=0 point of 61.0 m from the reference point at the east corner of the east dock. This area started at the last active anode from rectifier no. 1 and extended into the area covered by rectifier no. 2, which was not functioning at the time. Unfortunately, operational problems prevented the acquisition of adequate data at this location, so no results are reported.

At each location where the ROV was used, its cameras were used for a visual inspection of the anodes in the vicinity. This was done to verify anode locations and mounting integrity.

RESULTS AND DISCUSSION

Upon arrival, the rectifiers were operating as follows:

- Rectifier no. 1 (90-A capacity) was operating at a current of 33.8 A and a potential of 3.25 V.
- Rectifier no. 2 (90-A capacity) was turned on but not delivering any current.
- Rectifier no. 3 (90-A capacity) was switched off, but when it was switched back on it began operating at 40.0A and 3.15 V.

These three rectifiers were connected to 16 anodes each, and together protected the east dock seawall.

- Rectifier no. 4 (90-A capacity) was operating at 24.6 A and 3.17 V.
- Rectifier nos. 5 and 6 (older, air-cooled, 80-A capacity models) were locked, and currents could not be read.

Anodes were found and visually inspected at the following distances from the reference location: 47.5 m, 51.2 m, 56.1 m, 59.7 m, 63.4 m, 68.0 m, 72.5 m, 77.1 m, 82.5 m, 93.6 m, 102.2 m, 110.4 m, 116.3 m, 122.6 m, and 131.9 m. The anodes had broken loose and were missing at the last three positions. The anodes had broken away from the seawall and were hanging some distance from it at the four positions before that, as well as the anode at 68.0 m. The remaining anodes that were observed were affixed in one of the recesses of the seawall corrugations.

Figure 4 shows the results of the dipping cell measurements made next to the seawall. The lowest of the three curves in Figure 4 are measurements made at a depth of 4.4 m. The upper curve was made at a depth of 0.7 m, and the middle curve was made at a depth of 2.6 m. The overall shape of the curves shows excellent protection in the area of the first rectifier from zero to about 65 m, with potentials below –1.2 V. Less protection was afforded to the area supplied by the second nonfunctional rectifier, from 65 to 130 m, although potentials in this area were still below –1.1 V, indicating adequate protection. The area supplied by the third rectifier, from 130 to 200 m, was only slightly better protected than the area of the second rectifier, probably because the rectifier had been switched off before the measurements were taken. The area of the fourth rectifier, on the south dock above 220 m, had intermediate protection levels between the areas of rectifier nos. 1 and 3.

The effects of the anodes on local potentials is best seen in the curve at a depth of 4.4 m, with the local effects being unnoticeable at the surface. Areas next to the anodes were typically 0.1 to 0.2 V more negative than areas far from the anodes. The anode at 28 m shows no deviation; it was probably not operating properly. No local effects can be seen near the anodes connected to the second rectifier because they were receiving no current. Maximum potentials at the surface far from the anodes were only 0.02 to 0.06 V more positive than maximum potentials between anodes at a depth of 4.4 m. This shows that the seawall has minimal long distance potential gradients and short range gradients of only about 0.2 V.

Figures 5 though 8 show the results of the detailed measurements taken in a three-dimensional grid between two anodes to obtain a better idea of the short distance gradients. The anodes located at zero and 5 m had little effect on potentials at depths of 0.7 m (Figure 5) and at 2.6 m (Figure 6). The maximum effect was at a depth of 4.4 m (Figure 7). Even at this depth, near the centerline of the anodes, the potential difference between directly in front of an anode at 0.25 m distance from the seawall and halfway between anodes was only 40 mV. At 0.5 m from the seawall, this difference decreased to 30 mV, and at 1.0 m the difference was not measurable. At a depth of 4.9 m (Figure 8), 0.5 m below the previous data, the potential differences between areas close to the anodes and those far from the anodes were extremely small, 10 to 20 mV at 0.25 and 0.5 m from the seawall. Potential differences were not measurable farther away from the seawall.

Thus, local potential field gradients appear to have essentially disappeared at a distance of 1.0 m from the seawall and were negligible 0.5 m from the seawall.This point is further illustrated by the data in Figure 9, which were recorded while backing away from an anode location at a depth of –5.1 m, near the bottom. Potential became constant once a distance of 1 m from the seawall was reached; from 0.25 m to 1 m, the potential difference was zero to 20 mV.

CONCLUSIONS

Other than one rectifier that was broken and one that was turned off, the seawall cathodic protection system at the Naval Coastal Systems Center in Panama City, FL was in good condition and was adequately protecting the seawall, even with these problems. The dipping cell data indicated that local potential gradients were present near the seawall anodes. The detailed ROV investigations showed that these gradients were negligible at distances of 0.25 to 0.5 m from the seawall, a distance that most ships maintain with bumpers. These local potential gradients should not cause a problem for ship cathodic protection systems, even if the ship is docked with a controlling reference cell directly opposite a seawall anode.

The dipping cell data also indicated that potential gradients exist over longer distances along the seawall because a rectifier was shut down. This can also occur if the multiple rectifiers are not adequately balanced to the same potential. This can lead to potential differences over distances of roughly ship length proportions of several tenths of a volt, sufficient to cause control problems on a ship cathodic protection system. To avoid this problem, multiple seawall rectifiers should be periodically checked for proper operation and balanced to the same control potential. A ship should never be docked such that it bridges the area between two rectifiers that are not properly balanced to the same potential.

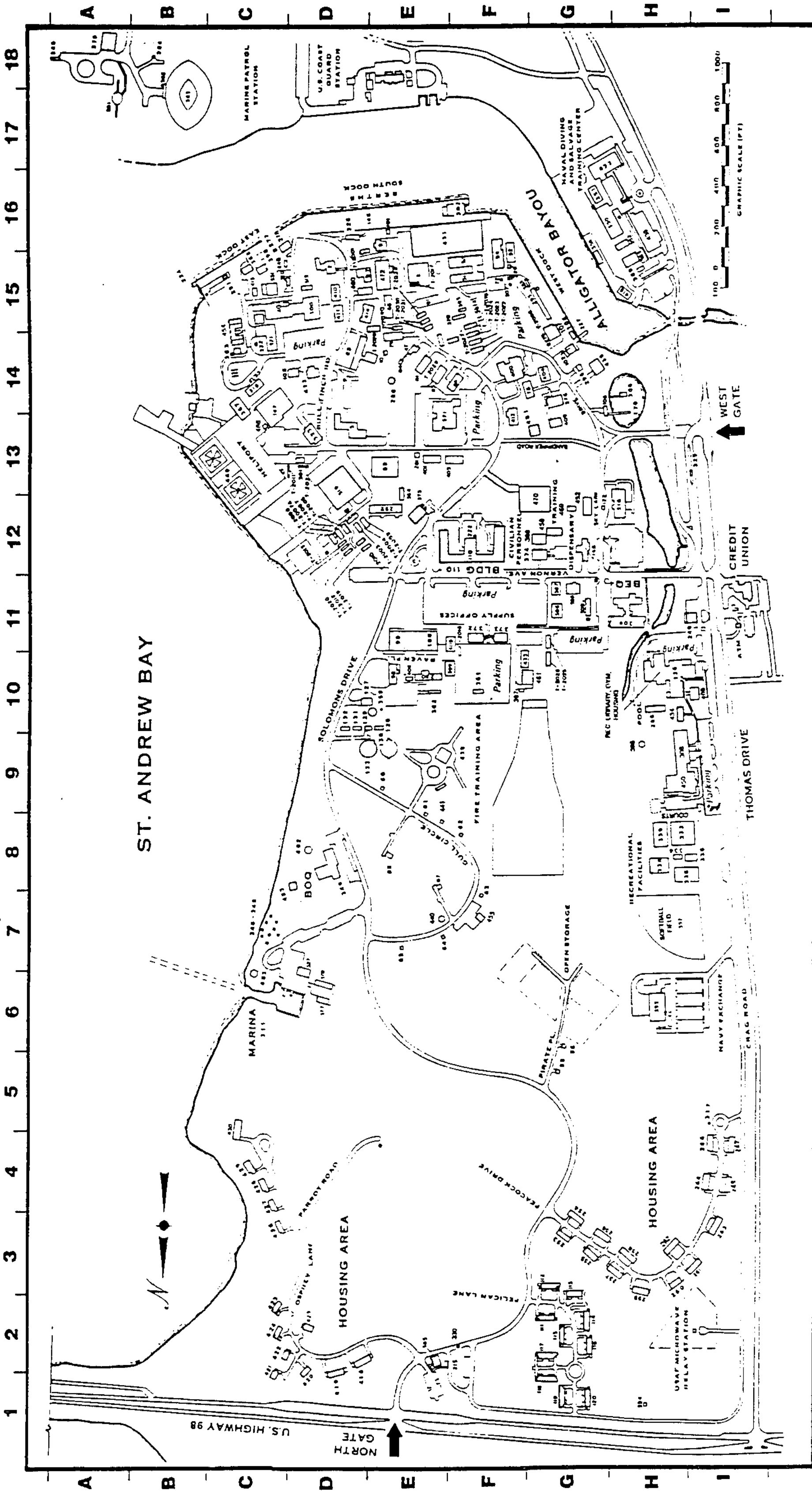

Figure 1. Relationship between seawall and surrounding bodies of water.

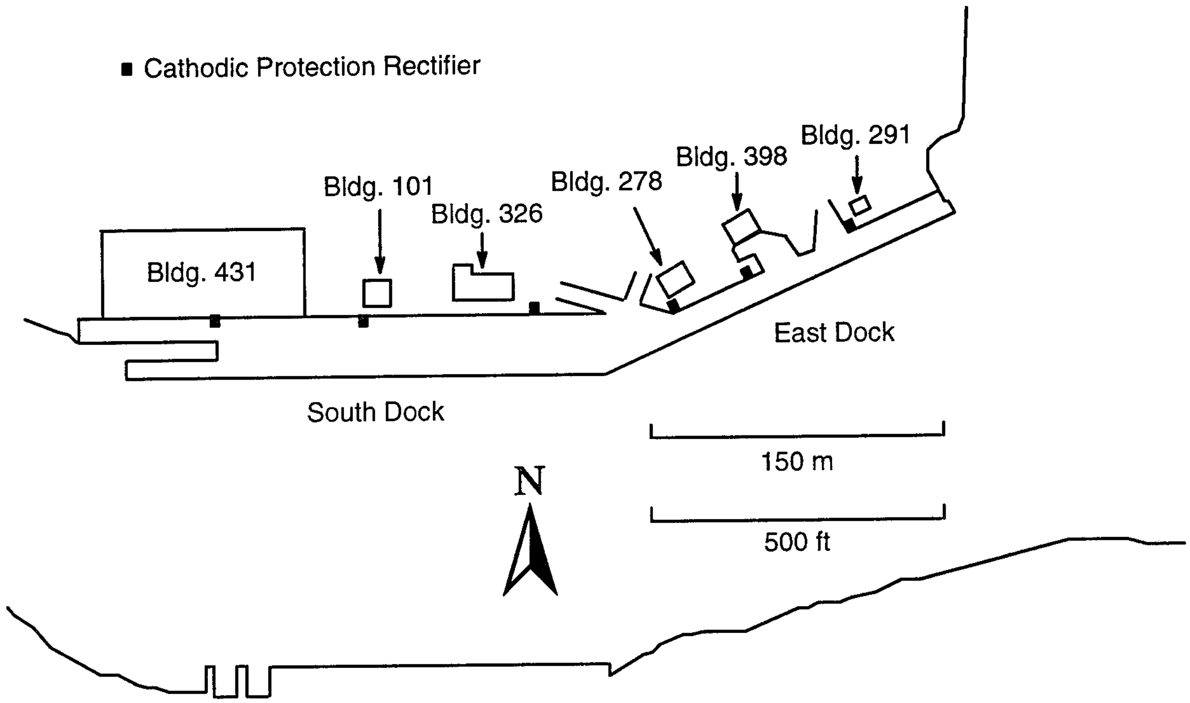

Figure 2. Detailed layout of the seawall with rectifier locations.

Figure 3. ROV used for potential measurements away from seawall.

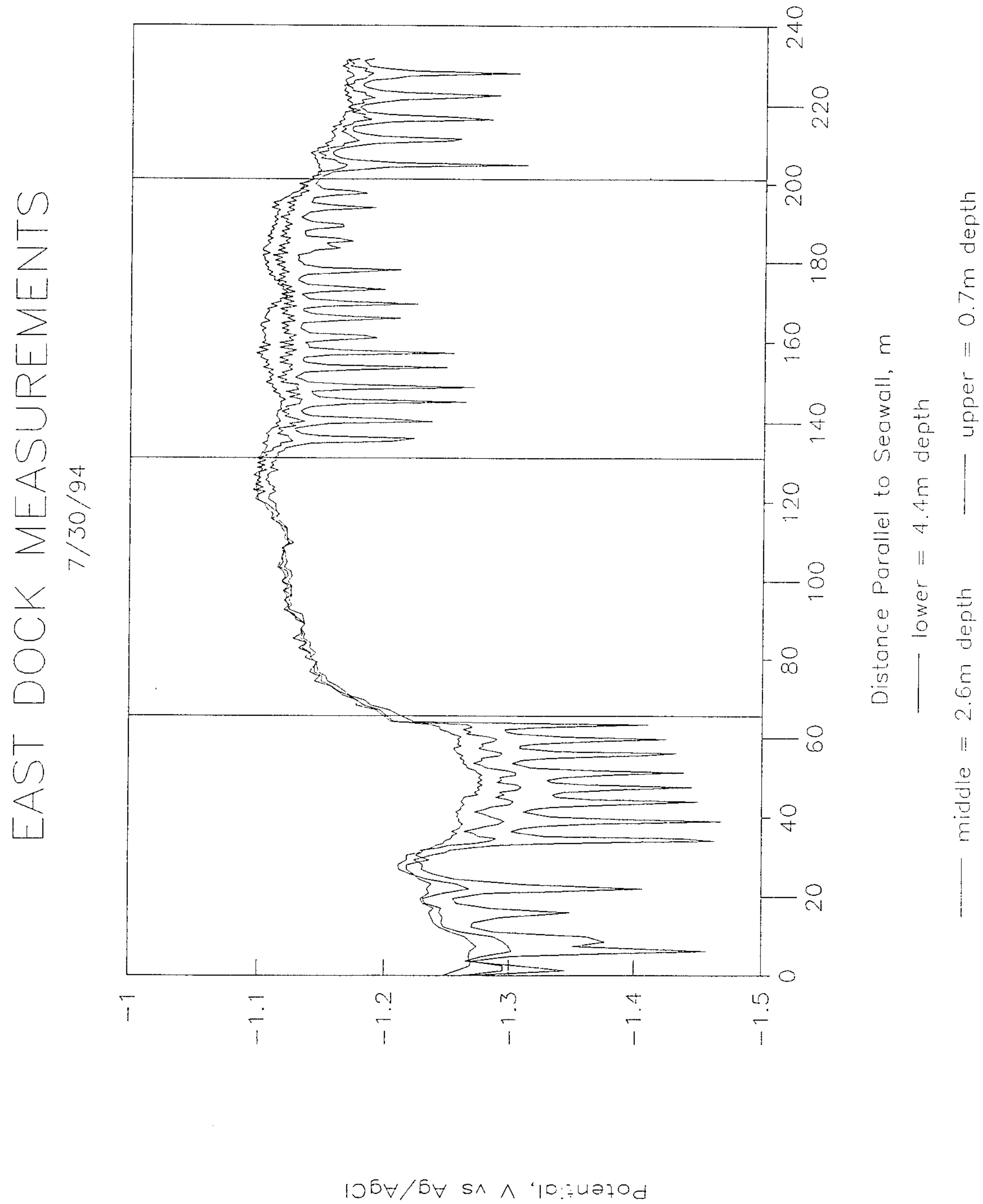

Figure 4. Dipping cell measurements.

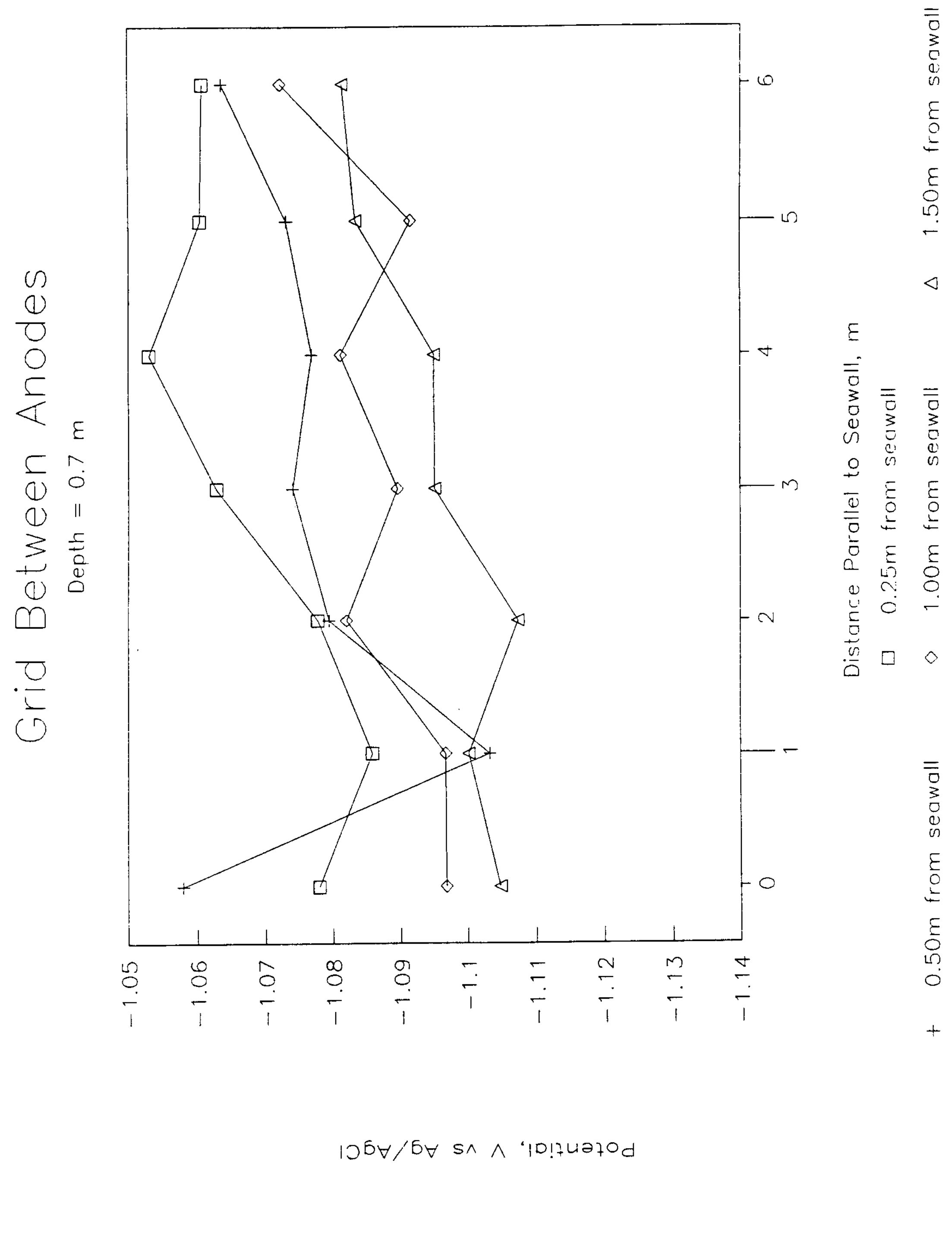

Figure 5. Detailed measurement grid between anodes—0.7 m depth.

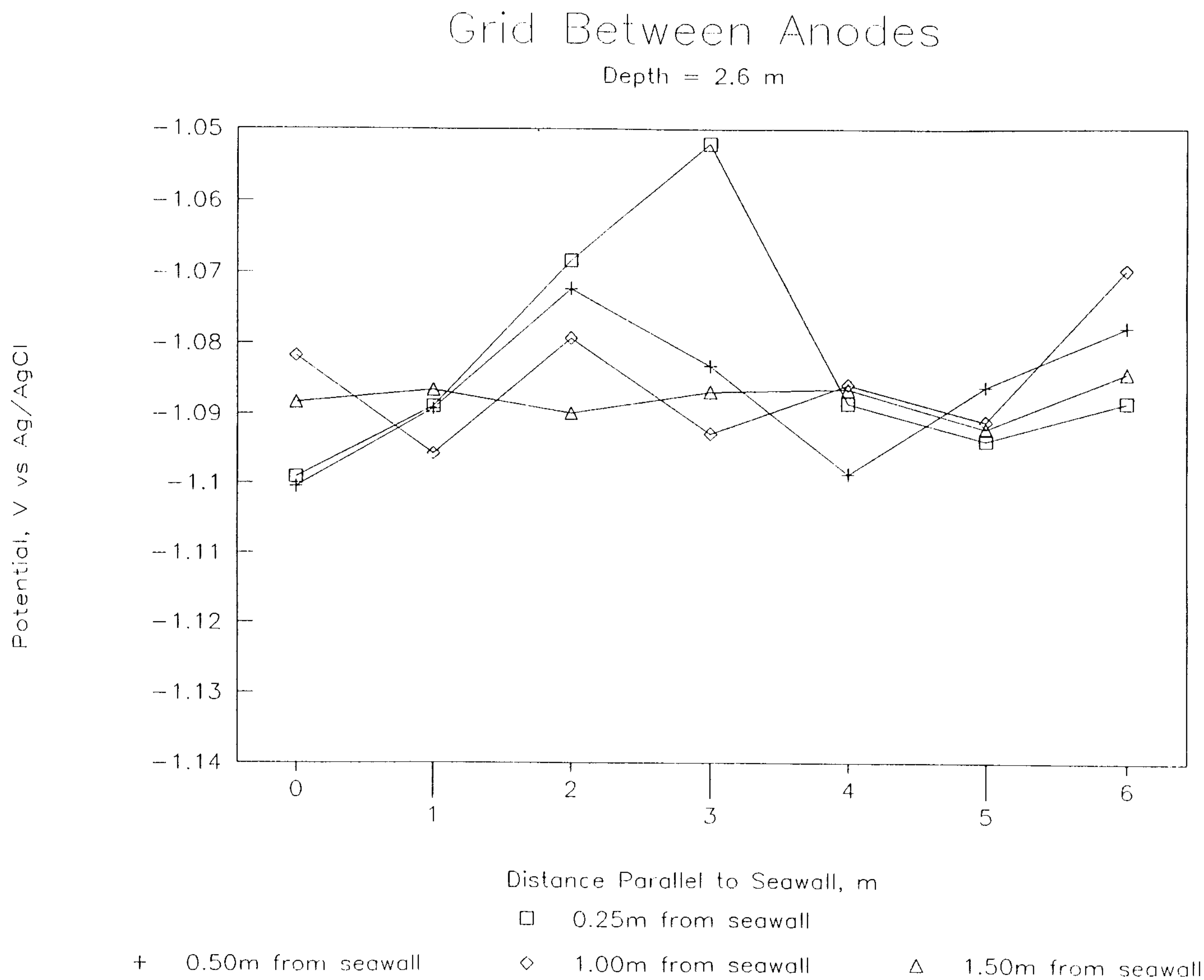

Figure 6. Detailed measurement grid between anodes—2.6 m depth.

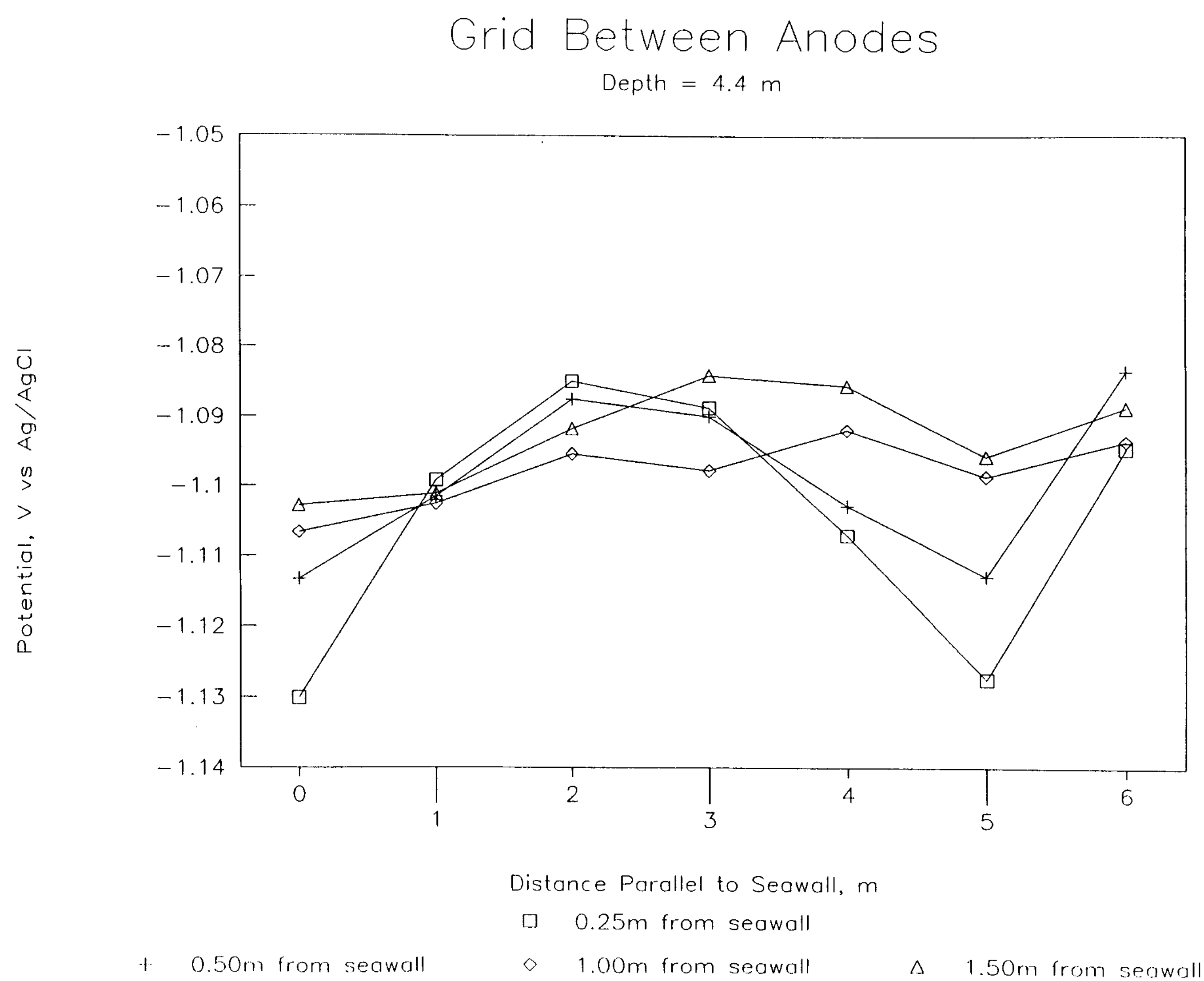

Figure 7. Detailed measurement grid between anodes—4.4 m depth.

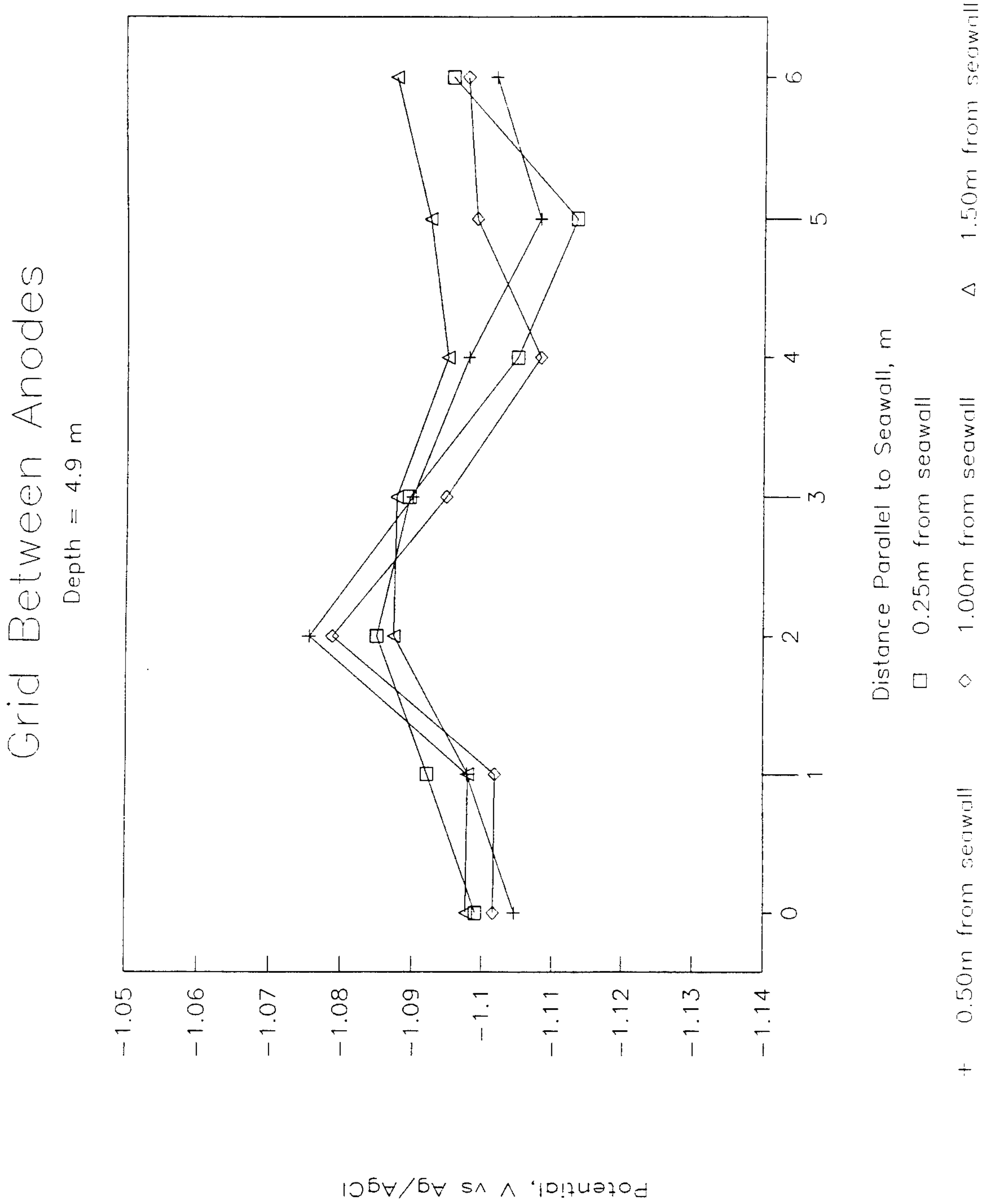

Figure 8. Detailed measurement grid between anodes—4.9 m depth.

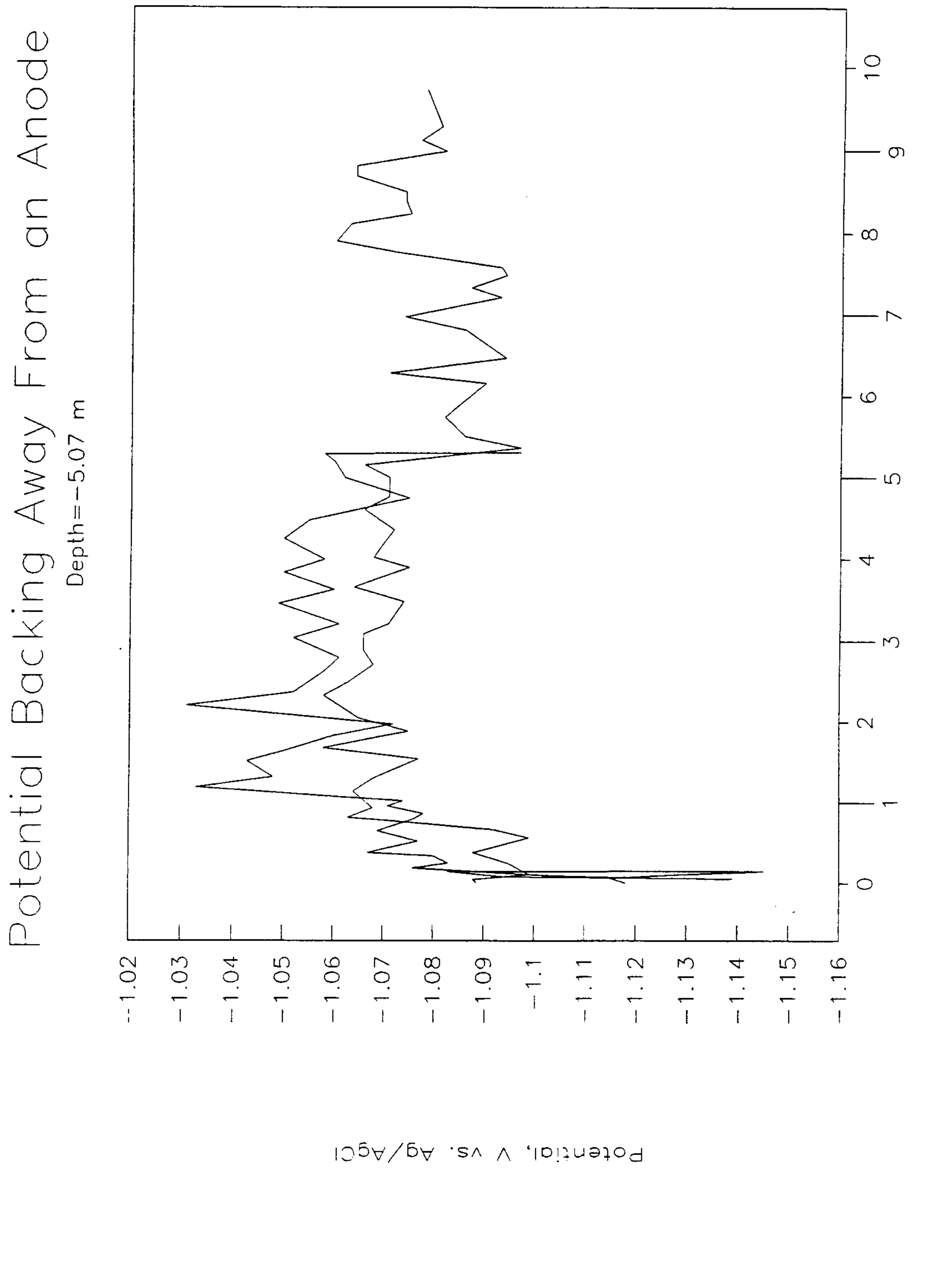

Figure 9. Potentials backing away from an anode at −5.1 m depth.

INITIAL DISTRIBUTION

Copies

1 Naval Research Laboratory
Key West, FL

2 Naval Research Laboratory
Washington, DC
- 1 Code 6130 (Thomas)
- 1 Code 6382 (DeGeorgi)

10 Naval Sea Systems Command
- 1 SEA 03M (Dr. A. Kaznoff)
- 1 SEA 03M1 (R. Parks)
- 1 SEA 03U3
- 1 SEA 03X72
- 1 SEA 08 (Berger)
- 1 SEA 08S (Kennedy)
- 1 PMS 350T (Peterson)
- 1 PMS 390
- 1 PMS 390T
- 1 SEA 92R

4 Office of Naval Research
- 1 ONR 332 (Sedriks)
- 1 ONR 332 (Sloter)
- 1 ONR 334 (Gagorik(
- 1 ONR 334 (Vogelsong)

2 Naval Civil Engineering
Laboratory
- 2 NCEL L43 (Jenkins)

2 Naval Coastal Systems Station
- 2 Code 30E (W. Muehl)

4 DTIC

CENTER DISTRIBUTION

Copies	Code	Name
1	011	
1	0113	
1	0114	
1	0115	(Caplan)
1	2020	(Ouimette)
1	3412	(Rice)
1	3422	TIC
1	60	(Wacker)
1	601	(Ventriglio)
1	602	(Morton)
1	603	(Cavallaro)
1	603	(Hardy)
1	61	(Holsberg)
1	61s	(Warf)
1	611	(Palko)
1	612	(Aprigliano)
3	613	(Ferrara)
1	613	(Aylor)
1	613	(Bieberich)
1	613	(Clarke)
1	613	(Davis)
10	613	(Hack)
1	613	(Hays)
1	613	(Jackovic)
1	613	(Mantel)
1	613	(Murray)
1	613	(O'Connor)
1	614	(Montemarano)
1	614	(Czyryca)
1	615	(DeNale)
1	62	(Eichinger)
1	624	(Bardsley)
1	624	(Clayton)
1	624	(DiGiovanni)
1	63	(Alig)
1	64	(Fischer)

CENTER DISTRIBUTION

Copies	Code	Name
1	641	(Montemarano)
1	641	(Bohlander)
10	641	(Lynn)
1	643	(Daugherty)
1	68	(Mueller)
1	6801	
1	683	(Barnes)
3	683	(Conrad)
1	684	(Anderson)
1	851	(Hood)
10	852	(Lynn)

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1995	Final

4. TITLE AND SUBTITLE

Interaction of Ship and Dock Cathodic Protection Systems Predicted From Potential Measurements of a Seawall at Panama City, Florida

5. FUNDING NUMBERS

Program Element 62761N
Task Area SF61541-591
Work Unit 1-2803-162

6. AUTHOR(S)

Harvey P. Hack and Dana C. Lynn

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Carderock Division
Naval Surface Warfare Center
Bethesda, MD 20084-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

CARDIVNSWC-TR-61—95/12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Carderock Division, Naval Surface Warfare Center technologists took potential (voltage) measurements on a seawall located at the Naval Coastal Systems Center in Panama City, FL to determine whether a large cathodic protection system on a pier or dock could cause stray current corrosion or cathodic protection control problems on a ship docked to the structure. The measurements were taken because, while the protection system on the seawall was providing adequate protection, one rectifier was not working properly.

Minimal local potential gradients were found near the seawall anodes. This should have had no effect on ships docked with the use of bumpers, which provide spacing of at least 0.5 m from the seawall. Rectifier shutdown or inadequate rectifier balance of the same potential can lead to potential differences over distances of roughly ship length proportions to cause control problems on a ship's cathodic protection system. To avoid this, multiple seawall rectifiers should be periodically checked for proper operation and balanced to the same control potential. A ship should not be docked so that it bridges the area between two rectifiers that are not properly balanced to the same potential.

14. SUBJECT TERMS

Cathodic protection, Stray current corrosion, Potential measurement, Remote operated vehicle, Piers, Docks, Seawalls, Potential gradients

15. NUMBER OF PAGES 24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Same as Report